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Plate I

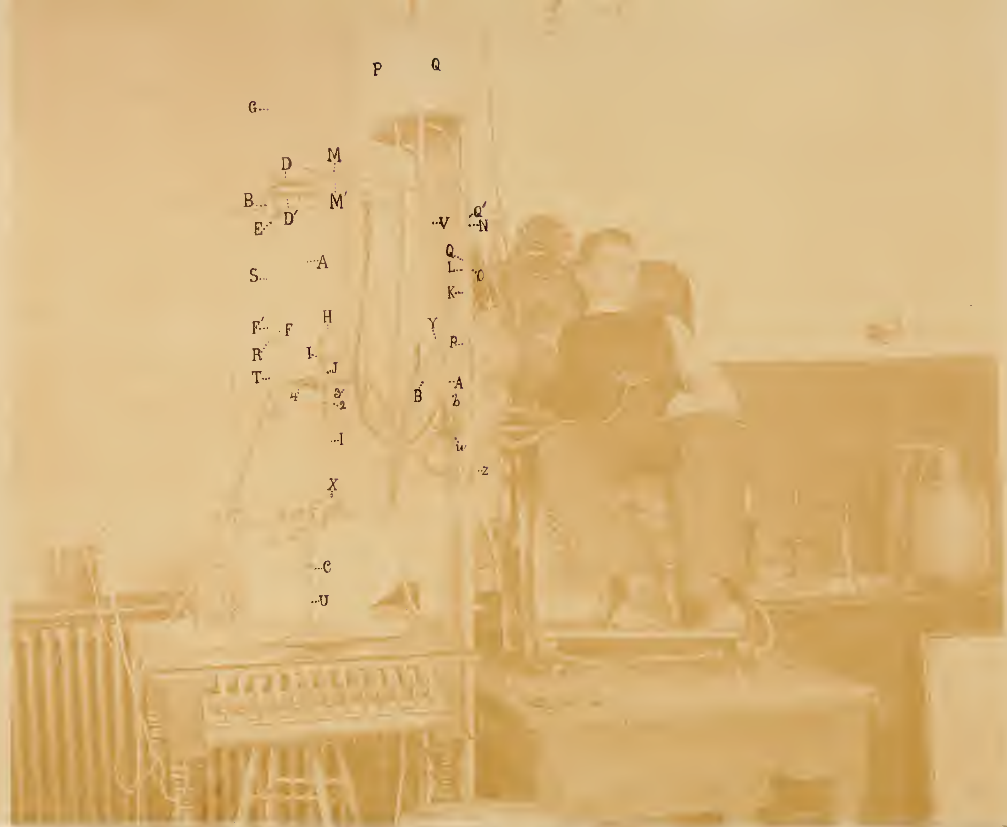


Plate II.

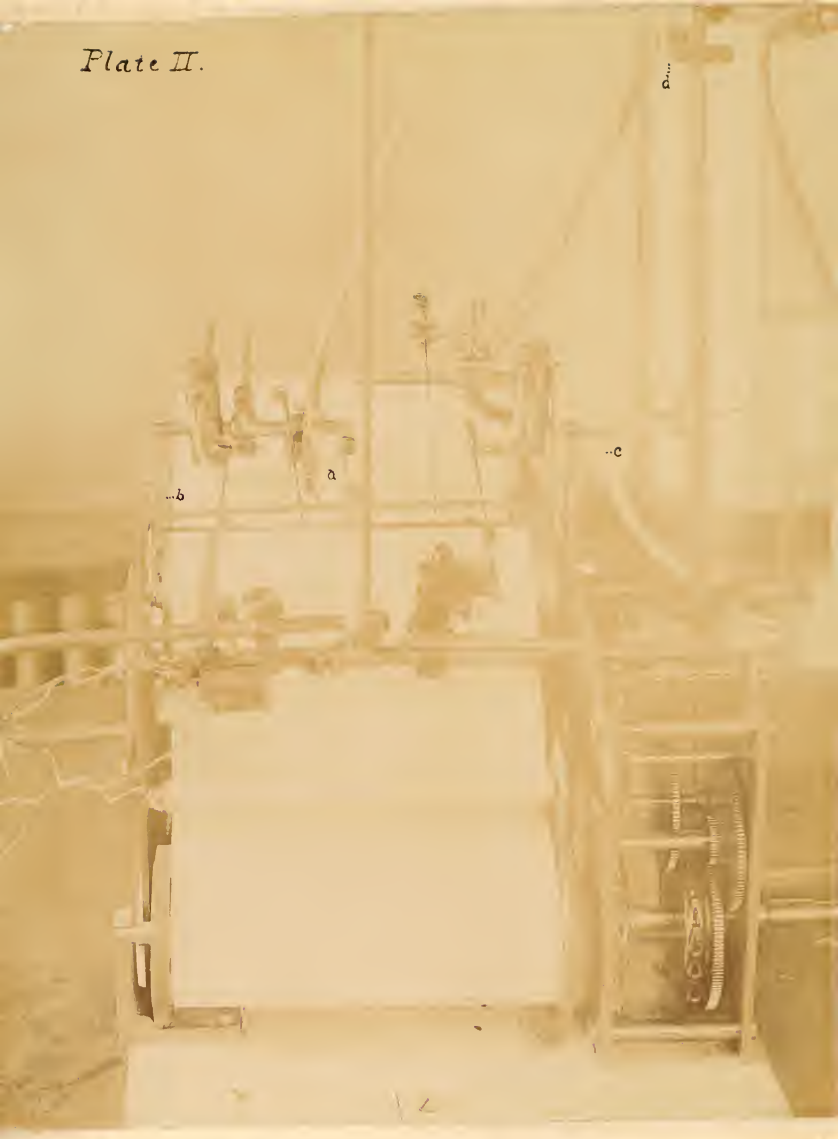
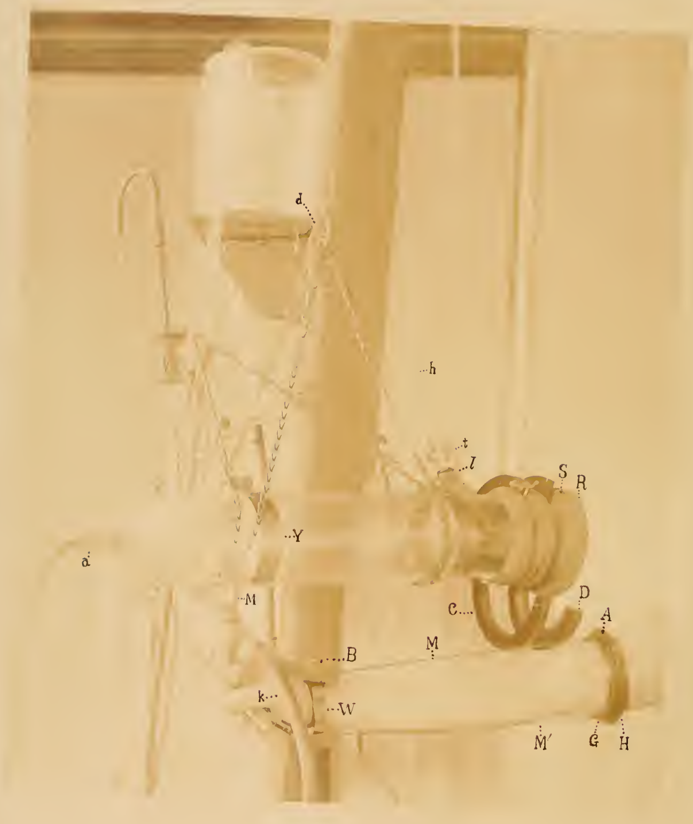


Plate III



JHU THESE
Shields,
T. E.
1975
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THE EFFECT UPON THE BLOOD FLOW, OF OLFACTORY SENSATIONS, OF MENTAL WORK, AND OF STIMULATION OF THE TERMINATIONS OF THE TRIGEMINAL NERVE IN THE MUCOUS MEMBRANE OF THE NOSE BY IRRITANT VAPORS. STUDIED BY MEANS OF A PLETHYSMOGRAPH ON THE ARM.

A THESIS SUBMITTED TO THE JOHNS HOPKINS
UNIVERSITY FOR THE DEGREE OF Ph. D.

BY

T. E. SHIELDS.

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Acknowledgement.

I wish to return my sincere thanks to Professor Howell, at whose suggestion this work was undertaken, and whose kind supervision and advice was a constant help and encouragement at every step of its progress. I am also indebted to him for his generosity in providing a subject for the first series of experiments. I am also indebted to Professor E.A.Pace of the Catholic University for many valuable suggestions on the Psychological aspects of the problem; and to Rev.C.A. Ramm for suggestions in the construction of the apparatus as well as for the three accompanying drawings.

I must also take this opportunity of thanking the young Gentlemen of St.Mary's Seminary,who generously placed their time at my disposal, acting as subjects for the second series of experiments; my thanks being due in a special manner to Messrs. Riedel and Beavan who not only acted as subjects in a number of experiments, but who also assisted me in the laborious task of tabulating the results, and plotting the curves.

Attempts have been made from time to time to determine the effects produced by various sensations on the circulation of the blood. In 1877, a series of experiments w~~ere~~as conducted by M,M. Couty and Charpentier, under the direction of M.Vulpian,I) in the hope of obtaining a more exact determination of these disturbances. They used curarized dogs with artificial respiration and recorded the results on a kymograph in the usual manner by means of a mercury manometer in connection with an artery. On stimulating the various organs of special sense they obtained cardio-vascular reactions similar in many respects to those usually obtained, by stimulating sensory nerves, but differing mark-

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I) De l' influence des excitations des organs des sens sur le coeur et sur les vaisseaux (~~research~~ recherches exp.faites dans le lab. d.M.Vulpian) note d.M M.Couty et Charpentier, presentée par M.Vulpian. Compt R.T.85.No.3.P.I3I.

edly from these in their greater variability in both form and intensity under the same stimuli.

Both pneumagastric nerves were then severed. Sensory stimulation continued to produce its usual effect on arterial tension, but ceased to produce any effect on the heart. This convinced them of the fact that the heart disturbances and vaso-motor changes were medi~~t~~ated by distinct mechanisms.

The cerebral cortex of fresh subjects was then shut out by pressure, by injection, and by light doses of chloral-hydrate. In every case stimulation of the organs of sense failed to produce any effect, either on the heart or on arterial pressure, while the direct stimulation of a peripheral nerve, such as the sciatic, continued to produce its usual effect. From these facts they concluded that the cardio-vascular disturbances accompanying sensory stimu~~al~~lation are not due directly to sensation itself, but to a contingent cerebral activity which they called emotion.

Experiments of this nature, however valuable in themselves, will hardly be regarded as sufficient data from which to draw conclusions as to the nature and extent of the cardio-vascular changes accompanying sensations in man. Even if it be granted that cerebral activity is the immediate cause of the cardio-vascular changes in both man and dog, it does not follow that these changes will be the same, since it is not even probable that the cerebral activities accompanying sensation in both cases are identical, either in kind or extent.

In 1880 Dogiel, I) attempted, by means of the plethysmograph, to study the effects of music on the circulation of the blood in man. The apparatus used contained so many sources of error that even the meagre results obtained can scarcely be regarded as reliable. It is to Mosso's 2) researches we are chiefly indebted for what

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I) Archiv fur Anat.und ~~Entwick~~.Physiol.Abt.1880,s.420 folg.

2) Krieslauf des Blutes,in Menschlichen Gehirn.Von A. Mosso Liepzig 1881.

definite information we possess concerning the correlation of cerebral function and cardio-vascular changes in man, but our literature on the whole subject of the changes produced in the circulation in response to various sensations is still very meagre. This is particularly true of olfactory sensations. The present research was undertaken in the hope of throwing some light on this problem.

The form of plethysmograph devised by Mosso was first used and the volume changes in the arm recorded on a drum-kymograph; but it soon became evident that several sources of error would have to be eliminated before accurate measurements could be obtained. The possibility of moving the arm into, or out of the cylinder during the experiment must be removed. It is not sufficient to request the subject to sit quietly, nor even to support his head and arm as Dogiel I) did. The voluntary effort required to sit immovable is it-

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I) Dogiel op.cit.p.429

self a disturbing factor in the circulation of the blood. Besides it is impossible to prevent movement of the arm for any considerable time, since normal respiration moves the arm. Mosso's I) plan of suspending the cylinder from the ceiling and allowing it to follow the movement of the arm is much better, but even here the inertia of the cylinder filled with water offers sufficient resistance to the movements of the arm to produce quite a perceptable error. I think it probable that the respiratory waves 2) often obtained by the plethysmograph are due in greater measure to this movement of the arm than to the change in its volume of blood. During the early part of the present research, I frequently obtained marked respiratory waves, but in every case I was able to trace them to this movement of the arm, and when the movement was prevented the respiratory waves were very much diminished if not en-

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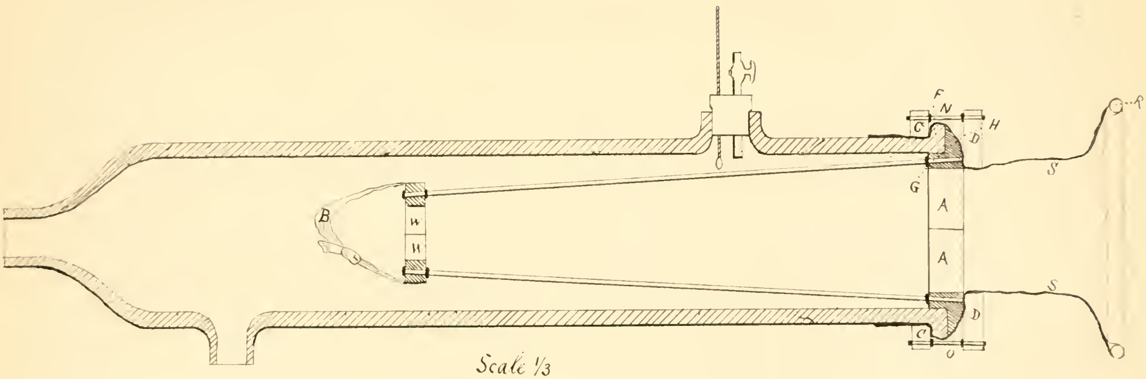
I) Mosso op.cit.p.
2) Dogiel op.cit.p.430

tirely removed.

A second source of error lies in the fact that every increase of pressure in the cylinder tends to force the arm out of it, and every diminution of pressure exerts an opposite influence. The play of these opposing forces is felt very distinctly on the enclosed arm during each pulse-beat; and when the resulting movement of the arm is prevented, the record of the pulse-wave is very much amplified. This source of error is still more marked in sudden, large vaso-motor changes; nor can it be eliminated by making the rubber sleeve so tight that it will not slip on the arm; for apart from the two obvious objections to this mode of procedure, that the arm should be oiled to prevent it from becoming endermitous, and that a tight sleeve interferes with normal circulation, the elastic sleeve itself lengthens and shortens in response to changing pressure in the cylinder.

There is still another source of error connected with this mode of closing the cylinder, which remains even after all movements of the arm into or out of the

Fig. 1



cylinder have been prevented. If the arm does not fit the mouth of the cylinder snugly, the portion of the elastic sleeve between the arm and the cylinder will yield to each change of pressure in the cylinder. The panting of this membrane in response to the pulse may be seen by the unaided eye. If the mouth of the cylinder be large enough to allow the elbow to enter, it will usually be found much too large to fit the upper arm. This was very conspicuously the case in the cylinder used by Dogiel.I) If the cylinder terminates over the large muscles of the fore-arm as Mosso 2) makes it do, it can be made to fit the arm snugly, but another source of error makes its appearance. Every movement of the enclosed fingers withdraws muscle from the cylinder or introduces muscle into it.

Figure I is a sketch of a device for removing these sources of error. The same is shown in plate III. The lettering is the same in both.

I) ~~Ste out~~.op.cit.p.429
2) Mosso.

One end of a suitable sized rubber sleeve S, is drawn over the arm-cylinder and fastened in position by a ligature. A metal ring R, large enough to pass readily over the flange is cemented into the other end of the sleeve. By the aid of this ring the sleeve is readily doubled back over the flange of the cylinder, where it remains until the arm has been put into position in the cylinder. A hard rubber wristlet W, provided with a hinge and clasp, fits around the wrist. A soft band B. passes from one side of this wristlet between the thumb and index finger and is buckled to the other side of the wristlet as tightly as comfort will permit. A second hard rubber ring A. provided with hinge and clasp, fits the arm above the elbow. This ring is rigidly connected with the wristlet by two metal rods N N'. A shoulder G, is cut into one face of this ring so as to make it fit into and against the mouth of the cylinder. The face H. of the ring is shaped so as to keep the rubber sleeve taut down to the point where it meets the arm. When the arm has been introduced into the cylinder and the

arm ring fitted into its place, the rubber sleeve is drawn down over it. Two hard-rubber rings C and D, rigidly connected by 2 metal rods N.N' and provided with hinges and clasps are then fastened outside the rubber sleeve. One of these rings C, rests against the flange of the cylinder; the other, D. fits tightly against the outer surface of the arm ring.

This arm-holder reduces to a minimum, if it does not entirely remove, the ~~re~~sources of error discussed above. All movements of the elastic sleeve are rendered impossible. The arm holder is made absolutely rigid to the cylinder. The wristlet with its tight band between thumb and index-finger prevents the arm from moving in the holder. As the enclosed arm cannot bend, no muscle can be withdrawn from the cylinder or introduced into it.

The arm was now found to change in volume about I c.c. at each pulse beat. This introduced a new difficulty in the recording apparatus. It will be remembered that in Mosso's I) plethysmograph, the volume

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I) Mosso sur la vessie Archiv Italien vol. p.

changes were recorded by means of a test-tube suspended in a beaker of water or some liquid of suitable specific gravity. The test-tube is counterpoised by a suitable weight carrying the recording needle and connected with the test-tube by two threads passing over a pulley. However well this arrangement may serve for recording slow changes, its inadequacy for recording such changes as we are here dealing with is evident. The introduction and withdrawal from the test-tube of a c.c. of water 50 to I00 times a minute sets up considerable motion in the water in the beaker, where every motion is a source of error, besides the system has a period of its own which sometimes neutralizes the pulse effects and at other times combines with them to produce greatly exaggerated excursions of the test-tube, as happens in the production of tone-beats. The great inertia of the system also prevents it from recording accurately such rapid changes in volume.

Th~~is~~e method ad~~a~~opted by Professor H.P.Bowditch,I)

I) Bowditch. Proceedings of Am. Academy [illegible] 79

of suspending the test-tube from a spiral spring is more convenient. This removes the error which in Mosso's plan, arises from the motion of the water in the beaker,It also materially lessens the inertia of the system. But the great inertia still remaining and especially the periodicity of the spring compelled me to seek some other method of recording. I had recourse to a water manometer of large bore,connected with the cylinder by a wide,indistensible tube. A light and very buoyant float 2) was used to carry the recording needle. This system, being rigid,and having no period of its own,except that due to the float,gave a fairly accurate record of the changes occurring in the volume of the arm but it introduced a new source of error which compelled me to abandon its use. The level of the water in the manometer-tube, determines the pressure which the water in the cylinder exerts on the arm.At the beginning of the experiment ~~every~~ the manometer may be set soas to exert the proper pressure. But in the course of the experiment every change in the volume of the arm will cause a change of

pressure on its surface. The arm sometimes changes 20 or 30 C.c. in volume in a few seconds. This, of course, causes a corresponding change in the level of the water in the manometer tube, which in turn alters very considerably the pressure on the arm, nor can this factor be neglected. I found that the change of pressure due to a few centimeters' change in the level of the water in the manometer caused a very large change in the volume of blood in the arm. This is what we would expect from the low blood pressure in the capillaries and veins.

Lehmann I) gives the following account of the apparatus used by him in investigating the effects of sensory stimulation. I quote his description in full since I shall have occasion to refer to the results obtained later on.

" Wir haben nun die Aufgabe auf die Bestimmung der Atembewegungen, des herzschlages und des Volumens eines einzelnen Gliedmasses, z.B. eines Armes

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I) Lehmann, Menschliches Gefühlslebens. Leipzig. 1892. page 77.

reduziert. Die erste Bestimmung ist mittels des Pneumographen leicht auszuführen, während die beiden letzten sich mittels Mossos Plethysmographen zusammen ausführen lassen. Dieser besteht aus einem an einen Ende geschlossenen Rohr, das eben weit genug ist, den Arm zu umschliessen, der durch einen Gummiärmel wasserdicht mit dem Rohr verbunden wird. Durch ein Seitenrohr wird das ganze Rohr, nachdem der Arm in die rechte Stellung gebracht ist, mit Wasser gefüllt, und hierauf wird das Seitenrohr durch einen Gummischlauch mit einem Mareyschen Schreibapparat (tambour enregistreur) in Verbindung gebracht. Jede Veränderung des Armvolumens bewirkt eine Hebung oder Senkung des Wassers, durch welche die Luft im Schlauch und im Schreibapparat beeinflußt wird, und die Bewegung wird dann von dem Stifte des Schreibapparates auf eine rotierende Walze (das Kymographion) gezeichnet."

This seems to be a Mosso Hydrosphygmograph I) in which the bottle for keeping the pressure constant

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I) Diagnostik des Pulses, von Dr. A. Mosso. Leipzig 1879.

has been omitted so as to compell the tambour to register both pulse and vaso-motor effects. In both these forms of apparatus the pressure on the arm is too high. The air cushion is at the top of the cylinder;the whole arm is consequently under a positive pressure of some centimeters of water. The under surface of the arm can scarcely be under a pressure of less than I2 c.m. If the cylinder be large enough to extend above the elbow, as it should do in order to escape a source of error mentioned above, this pressure is likely to be still higher.

The form used by Lehmann introduces another grave source of error. In dispensing with the pressure bottle,the tambour and cylinder are rendered a closed system, in which every change of volume in the arm alters the pressure on its surface. If, as sometimes happens 25 or 30 c.c. of blood be added to the volume of the arm, the distension of the membrane of the tambour,necessary to make room for this increased volume of blood, would exert a considerable pressure

on the arm.

Besides the sources of error enumerated in connection with each of the forms of apparatus discussed above there is a defect common to them all. We have seen that the changes in volume of blood in the arm are due to at least two distinct sources; changes in the heart's action, and changes in the caliber of peripheral vessels. It is therefore highly desirable that the record of these two effects be kept as distinct as possible. Whenever, as is the case with each of these forms of apparatus, the same needle is made to record the pulse and the gross volume changes, these effects partially mask each other and do not stand out as distinctly as they should. This is illustrated very well by many of the curves published in Lehmann's work. I have a large number of similar curves in my own possession, which I obtained by the use of these forms of apparatus.

From what has been said, it is evident that an efficient apparatus for recording the volume changes

in the arm, must at least, meet the following three requirements, I st. The pulse and vaso-motor effects should be recorded separately. 2 dly. The apparatus for recording the rapid and rhythmic changes of volume due to the pulse should have very little inertia and no periodicity. 3 dly. The pressure exerted on the arm should be as nearly normal as possible, and must remain constant during all changes of volume which may occur in the arm. These requirements are met fairly well by the following arrangement.

A long metal tube A (Plate I) is slipped over an upright, U. to which it is fastened by a clamp C. The top of the upright is held in position by two metal rods M.M.' which make~~s~~ it rigid to the wooden screen interposed between the subject and the Kymograph. A short metal tube B, is supported in a vertical position by two clamps D.D' which make it rigid to the upper end of tube A. One end of a long close spiral S. of No.5 piano-wire is slipped over the lower end of the tube B. and fastened to it by a clamp E. Two wires F.F.' pass down from

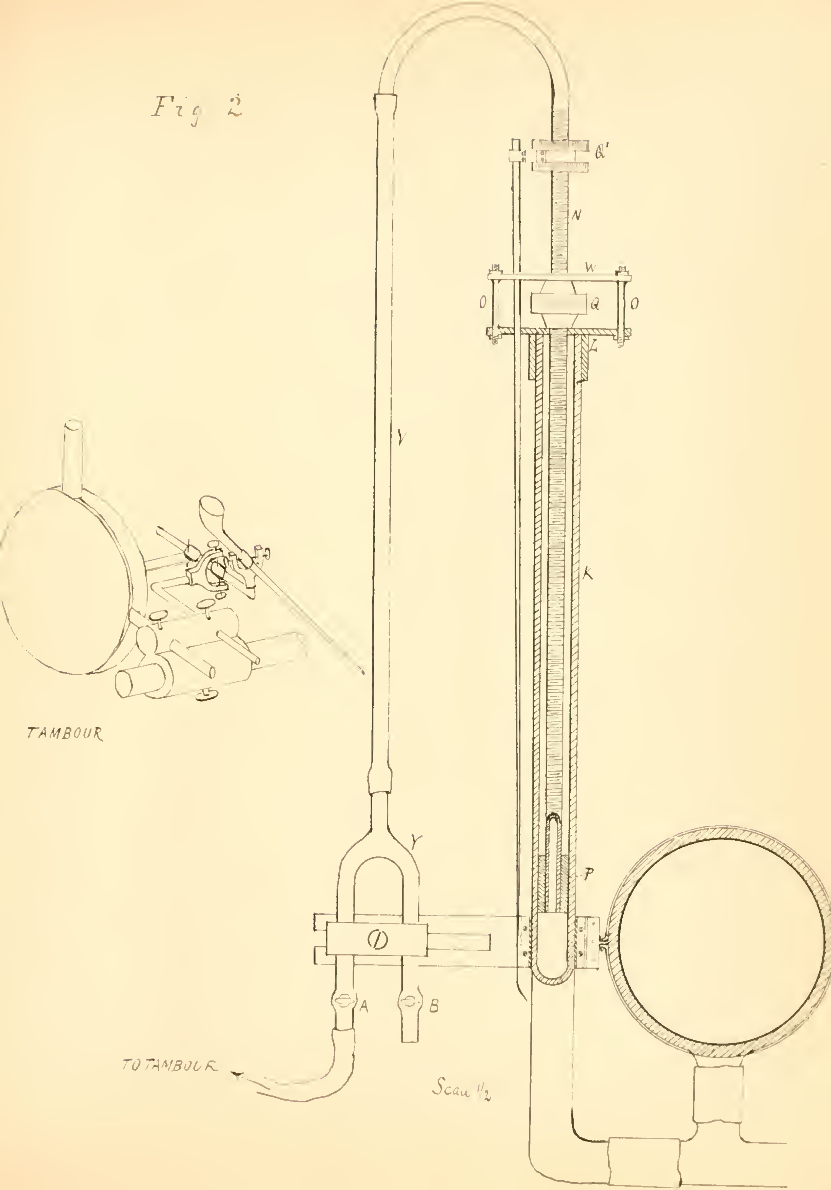
the free end of the spiral and are fastened by two small binding screws to a light,hard rubber ring R, ~~2~~ 1 inch~~es~~ in diameter. By suitable sized cork-collars, various sized, test-tubes may be suspended from this ring.The slipping of the wire under clamp E, permits the length of spiral to be so adjusted that the level of the water in the suspended test-tube will remain constant while the quantity of water in the test-tube varies. One arm of a long glass syphon G, is passed down through tube B, thence through the center of the spiral S, and dipped a few Millimeters beneath the surface of the water in the test-tube T. The syphon is centered and held in position by six set~~s~~ screws passing through tube B. An indistensible tube H,I, connects the other end of the syphon with the arm cylinder. The four way J, interjected in this tube will receive attention later.

This is essentially the same as the apparatus described by Professor Bowditch, to which reference has. already been made. It's inertia unfits it for recording the changes in volume due to the pulse.Its periodicity

combining with the rhythmic pulse at times neutralizes the pulse effects and at other times combines with them to produce greatly exaggerated excursions of the test tube. The pulse and vaso-motor effects also, partially mask each other. The pulse effects are the disturbing factor in each case, if they be removed from the test-tube and recorded separately, the instrument is well adapted for registering the vaso-motor effects.

This is attained by the following device; a wide glass piston-tube K, is supported in a vertical position beside the arm-cylinder, with the bottom of which it communicates freely. The upper end of the tube is encased in a metal cap L, which is perforated to allow free play to the hollow piston-rod N, and free communication between the air in the upper end of the piston-tube and the atmosphere. From this cap two metal rods O, O, parallel with the piston-tube extends upward about I inch and hold in place a washer W, which encircles the piston-rod. Between the washer and the cap a milled nut Q, fits on the piston-rod which is threaded from end to end.

Fig 2



The piston-rod N, is a metal tube I/8 inch in diameter which extends through an other-wise air tight piston P, in the piston-tube. A small indistensible tube V, connects the upper end of the piston-rod with a Marey tambour X. A T-way, Y, provided with 2 stopcocks A,B, interposed in the course of this tube permits connection between the air cushion below the piston and the tambour or the atmosphere to be made or broken as desired. A milled nut Q.' fitting the piston-rod above the washer, carries an indicator which passes down through a perforation in the washer, thence through a perforation in the flange of the metal cap and terminates below the level of the piston. The distance between the point of the indicator and the lower surface of the piston is the vertical height of the air-cushion. It can be set at any desired distance by means of the nut Q.' Since the indicator is carried by the piston-rod, the distance between it and the piston remains constant whatever alterations may be made ~~level of th--~~ in the level of the piston. The level of the water in the piston-tube when the air

cushion is in communication with the atmosphere, indicates the pressure exerted by the water on the surface of the enclosed arm. For convenience in registering this pressure a centimeter scale is affixed to the side of the piston-tube.

The arm cylinder is of the usual form. A flexible metal band Y (Plate II), encircles the cylinder near one end, and is closed over the upper surface of the cylinder by a nut and bolt, To this bolt are also fastened 2 chains which pass around the cylinder in opposite directions and thence through a ring d, which is suspended some distance above the cylinder. The chains are doubled back and hooked on themselves at desired lengths. The other end of the cylinder is suspended in a similar manner from the same ring. These chains serve to keep the cylinder in a horizontal position, and to prevent it from rotating. A 5 th chain from which the ring d, is suspended passes through a pulley fastened to the ceiling thence down through a ratchet which is supported at convenient height. By turning this ratchet the cylinder is raised

or lowered to suit the comfort of the subject.

Besides the opening through which the arm is introduced, the cylinder is provided with 3 other smaller orifices. Through one of these, a situated on the end of the cylinder, communication is made with the suspended test-tube. A second orifice l, provided with a tight fitting rubber stopper through which 2 perforations have been made is located on the upper surface of the cylinder. A glass stop-cock t, is fitted into one of these perforations. The bulb of a thermometer h, is introduced through the other. On the under surface of the cylinder is a 3rd orifice M, into which is fitted one branch of a large T-way. A 2 nd branch of this T-way communicates with the lower end of the piston-tube. The 3rd branch is connected with the tube k, for filling and emptying the cylinder.

I have found the following method convenient for filling and emptying the cylinder; for regulating the temperature and pressure of the water; and for adjusting the instrument.

The piston is raised or lowered by turning the

milled nut Q (Plate L), until the point of the indicator stands at the level to which it is desired to bring the water in the piston-tube. 2 supply-jars P.Q, one filled with hot water, the other with cold water are placed on a shelf attached to the screen above the level of the test-tube-syphon G. 2 syphons connect these jars with two branches of a large three-way stopcock W, which permits the hot and cold water to be mixed in the desired proportions. The bulb of a thermometer b, for indicating the temperature of the water is placed in the tube which conducts the water from three-way W,to one branch of a 2 nd large three-way z, A tube connects a 2 nd branch of this three-way with the arm cylinder, another tube leads from its 3rd branch to the sink. This three-way allows the water to pass from three-way w, to the cylinder, or from the cylinder to the sink, or from a hydrant-tap to the supply jars,as may be desired.

The four-way J, each branch of which is provided with a stopcock, is made rigid to the tube A,at

a level somewhat lower than that of the arm cylinder. One of these stopcocks I, opens into the test-tube-syphon 5, a 2 nd 2, communicates with the arm cylinder, a third 3, is connected by a syphon with one of the supply jars. A tube from the fourth, 4, leads to the sink.

When the subjects arm has been coated with vaseline, and placed in the arm cylinder, as directed above, stopcock t, on the upper surface of the arm cylinder is opened to allow the air to escape. Stopcocks A, and B, are closed to cut off connection between the air cushion and the atmosphere and tambour. Stopcocks I and 2, on the four-way are opened and stopcocks 3, and 4, closed. Three-way stopcocks w, and z, are adjusted so as to allow water of the proper temperature to enter the arm cylinder. When the cylinder is within a few c.c.s of being full the supply of water from this source is shut off, and a strong clamp placed on the supply tube at the point, where it meets the cylinder, to prevent any possible error that might otherwise arise from leakage or from distention of the supply

tube. Stopcock 3, on the four-way, in now opened and water allowed to flow into the cylinder until it is filled when stopcock t, is closed to prevent air from re-entering the arm cylinder, stopcock 2, on the four-way is closed at the same moment to prevent increase of pressure on the arm while the test-tube-syphon is being filled. When the test-tube is partially filled stopcock 3, is closed and stopcock 2, opened. If the test-tube is too full at any time water may be drawn off by opening stopcock 4. Stopcock B, is now opened, thus establishing free communication between the air-cushion and the atmosphere. The water in the piston-tube will now rise to the same level as that in the test-tube. Tube A, carrying the test-tube and its appurtenances, is slowly raised or lowered on the upright until the level of the water in the piston-tube reaches the point of the indicator. Stopcock B, is then closed and stopcock A, opened, thus putting the air-cushion in communication with the tambour. The lever of the tambour will now give a magnified record of the

changes in the level of the water in the piston-tube. If the resistance offered by the long narrow tube H,I, to the rapid passage of water between the test-tube and the arm cylinder is not sufficient to prevent the changes of volume due to the pulse from moving the test-tube, this resistance is increased to the desired extent by partially closing stopcocks I, and 2, on the four-way. The small and rapid changes of volume due to the pulse are consequently recorded by the tambour alone, while the slower and larger volume changes, freed from pulse-waves, are recorded by the motions of the test-tube, on the same principle that the height of the tide is recorded by the level of the water in the vertical pipe of a tide-gauge, while the separate waves are prevented from influencing this level by the resistance which the small holes in the bottom of the pipe offer to the rapid passage of water.

This form of apparatus reduces very much the sources of error discussed above. The suspended test-tube is entirely freed from the error due to the perio-

dicity of the spring. The inertia of the system ceases to be a grave source of error owing to the slowness of the motions which it is now required to execute. The tambour relieved,for the most part, from the disturbing factor of large volume changes, gives a fairly accurate record of the pulse waves. The chief source of error remaining is the pressure exerted by the water on the arm. It is, of couse, impossible to have an arm immersed in water under perfectly normal pressure. When the level of the water in the piston-tube is that of the middle of the arm, the lower half of the arm will be under a positive pressure of a few centimeters of water, and the upper half will be under a like amount of negative pressure. I have found these conditions most favorable.

Each pulse-wave is accompanied by a slight change of pressure on the arm, due to the resistance which the water in the cylinder offers to the entrance of the wave. This resistance is made up of several factors: I st the inertia of the volume of water to be moved: 2 ndly, the

force of gravity to be overcome in slightly raising the level of the water in the piston-tube: and 3 dly, the resistance offered by the air cushion to change in the level of the water in the piston-tube. The last named resistance is due to the tension of the membrane of the tambour, and to the inertia and friction of the recording lever. These sources of error are quite small, but they still exist and should be taken into account in calculating results. The resistance offered by the air cushion has been rendered very slight by reduction in the weight and friction of the recording lever, and by the delicacy and low tension of the tambour-membrane. The inertia of the mass of water to be moved may be reduced somewhat by so changing the form of the arm-cylinder as to diminish the distance between the surface of the water in the piston-tube and the point where the expansion of the enclosed arm first occurs. The wider the piston-tube the less the change in the level of the water caused by the pulse-wave, but the pulse recorder becomes proportionately more sensitive to vaso-

motor changes. When there is a sudden large change in the volume of the arm the vaso-motor recorder cannot take care of it rapidly enough. There is, in consequence, a temporary variation in the level of the water in the piston-tube, which interferes somewhat with the pulse recorder, and changes the pressure on the arm. The influence of this disturbing factor, which I have not yet been able to entirely eliminate, will receive attention, when we come to discuss the results.

In the early part of the investigation I used a Ludwig drum-Kymograph, with smoked paper, for recording the curves. A light needle, a couple of inches long was fastened by a small binding screw to the rubber ring R, carrying the test-tube. The point of the needle was held against the drum by a weighted silk thread. The slight friction of the point of the needle against the paper and against the thread, caused the test-tube to depart slightly from the vertical plane. This causes a loss of motion at the point

of the needle. The longer the needle the greater this loss, both because it produces a larger deflection in the test-tube and, because it magnifies more the record of this deflection on the paper: and if the needle be short, the test-tube will be in the way of the other recording levers.

The points of the tambour-lever and time-marker were made to write in the same vertical line with the test-tube needle. It is highly desirable to have a simultaneous record of the respiration and an automatic stimuli-signal, but owing to the difficulty of keeping five needles recording simultaneously in one vertical line on the drum, the latter two **were** dispensed with. It soon became evident, however, that this plan of recording presented another grave difficulty.

Spontaneous changes, or at least changes not due to sensory stimulation, were continually appearing in both vaso-motor and pulse curves. It was therefore, necessary to have a continuous record of the changes going on in the arm for sometime before and after stim-

ulation, in order to be able to differentiate them from any sensory reactions which might appear. This is impossible with the Ludwig drum-Kymograph: for if it be made to travel fast enough to bring out the pulse curve, the paper will be used up in three or four minutes, and it will be necessary to stop and put on fresh paper. An ink record on a continuous band of paper is evidently what is needed. The chief difficulty in obtaining such a record is the resistance to be overcome in moving the vasomotor and pulse pens. I was unable to reduce this sufficiently in the case of vertical Kymographs for continuous paper, and accordingly built a horizontal Kymograph, the details of which are sufficiently shown in plates I, and II. By special contrivances for suspending and moving the pens the resistance was reduced within the limits of that offered by the smoked paper.

A light plate of ~~a~~ aluminium foil a (Plate II), is cut in the form of a cross. The two ends of the transverse beam widen out and are bent so as to clasp tightly the tube of a glass pen. The ends of the other beam of the cross

are bent into hooks; from one of which a thread passes over ~~under~~ a pulley b adjusted to the side of the Kymograph, and is held taut by a small weight. From the hook on the other end of the beam a thread passes under a pulley adjusted to the other side of the Kymograph, and thence vertically to a violin-key which turns in a cork-holder d cemented to the bottom of the test-tube. This key is turned until the pen rests over the center of the paper. A thread, fastened to the bulb of the pen, passes vertically to a similar violin-key which is supported in proper position. The tube of the pen, at a point somewhat beyond where it leaves the holder, is bent downward through an angle of about 45° The key to which the vertical thread supporting the bulb of the pen is fastened is turned until the point of the pen just touches the paper. The pulleys are so adjusted that the upper portion of the pen will be about horizontal. The thread passing between the pulleys is horizontal also, except for the sag in the middle, caused by the weight of the pen. As the pen moves from either pulley towards the other it de-

scribes a curve, due to the sag in the horizontal thread. This curvilinear motion is neutralized in the point of the pen by the pendular motion of the bulb, due to the thread from which it is suspended, the factors in this adjustment being the extent of the sag, the length of the pendular thread, and the respective distances of the point and bulb of the pen from the horizontal thread. The extent of the sag is controlled by the size of the weight on the end of the thread. The length of the pendular thread is regulated by raising or lowering the key-holder from which it is suspended. The distance of the ends of the pen from the horizontal thread is controlled by moving the pen in its holder.

The friction between the point of this pen and the paper is very small since the point need not actually touch the paper; The capillary attraction between the paper and the meniscus being sufficient to cause the ink to flow, if the pen be properly made. But even when the point of the pen actually touches the paper it does so very lightly. If the point of the pen be

lifted by a finger until the sag leaves the horizontal thread, half the weight of the tube of the pen will rest on the finger. If the finger be now gradually lowered, the weight on it will be found to progressively diminish and finally to disappear, having been thus shifted to the horizontal thread. This gives very great buoyancy to the point of the pen and reduces friction to a minimum.

The pulleys are large and very light and are pivoted in a manner similar to the balance-wheel of a watch. Their friction is thus rendered very small. The inertia due to the pen its aluminium holder and the light weight on the end of the horizontal thread is relatively a very small addition to that of the test-tube, partially filled with water, but the inertia of this whole system, large as it is, has very little influence on the accuracy ~~to~~ of the record, owing to the slowness of the motions which it describes.

The tambour of the pulse-recorder (Plate II. figure 2) is supported with its membrane vertical. The motions of this membrane are communicated to one end of a light aluminium lever

which, just after passing through a pivot whose axis is vertical, bends upward at a right angle, and after running in this direction about I in., supports a second pivot whose axis is horizontal and perpendicular to the long axis of the paper. A light glass pen, with long tube, is passed through this pivot and fastened to it when the bulb of the pen is directly over the axis of the first pivot. The motion of the membrane will now impart a magnified horizontal movement to the point of the pen, while its bulb being in the axis of the pivot only undergoes a very slight rotary motion. The 2 nd pivot allows the pen to move freely in a vertical plane. Ink is now poured into the bulb of the pen until the point of the pen barely rests on the paper. The friction here is very slight. The inertia of the system is not great. It may.be reduced still more by making the pen of aluminium instead of glass. I have not yet attempted this, as the glass pen thus pivoted and counterpoised gives me as accurate a pulse curve as I need for present purposes.

The pens for the pneumograph, time-marker, and

signal are pivoted in a slightly different manner, but one which involves the same principle. The bulb of the pen with the ink which it contains acts in each case as a counter-poise to the long tube of the pen, thus causing the point to rest on the paper as lightly as desired. A horizontal movement is imparted to the point of the pen by a fork on the end of the tambour lever, or of an armature of an electro-magnet, as the case may be. For this purpose the pen must be free to move around two axes, one vertical and one horizontal.

The points of the 5 pens are adjusted so as to fall in a line perpendicular to the long axis of the paper. The test-tube used in the vaso-motor recorder was of such a caliber that 3 c.c. of water moved it I C. m. The paper travelled from right to left, the time record is nearest the test-tube, and consequently at the bottom of the paper. Movement of the vaso-motor or pulse pen towards the bottom of the paper represents diminishing volume of the arm, and conversely. I used the time record as base line in calculating the volume changes. If d

represents the initial distance in centimeters between the point of the vaso-motor pen and the base-line and d' its distance in any subsequent position, then $d' - d \times 3 = V$, where V is the volume change in cubic centimeters. If, at any time during the experiment, the test-tube is becoming over filled, stopcock 2, on the four-way, is closed and stopcock 4 opened until the desired amount is drained off. Stopcock 4 is then closed and stopcock 2 opened, and the fact noted on the paper. The point of the pen, of course, records the volume drawn out, which must be added in calculating subsequent changes. If the test-tube is in danger of being emptied water is introduced through stopcock 3, in a similar manner; and the amount subtracted in all subsequent calculations.

Being thus enabled to obtain, what I believe to be, a fairly accurate record of the changes which actually occur in the volume of the arm, I proceeded to study the influences which determined these changes, in the hope of being able to eliminate some of them, and to differentiate the changes which would remain from any odor reac-

tions I might obtain.

I first determined empirically what temperature of water, and what pressure on the arm, would maintain the most constant volume of blood in the arm. This in the case of pressure I found to be, as has already been stated, when the level of the water in the piston-tube was about that of the middle of the arm. (The point of the indicator resting between 10 and 12 on the centimeters scale) When I used pressure lower or higher than this, the arm exhibited a tendency to increase or diminish in volume. The proper temperature of water I found to be between 30° and 34° C. according to the temperature of the room and of the arm of the subject. I found that this temperature kept the volume of the arm more constant than any other, and I found also that the temperature of the water in the cylinder remained constant throughout the experiment, whereas if the temperature be higher at the beginning it will sink during the experiment, and conversely, if the initial temperature be lower.

Every muscular movement on the part of the subject is accompanied by a change in the volume of the enclosed arm. After the experiment had continued for about half an hour, large and frequent changes of volume usually occured, which I attributed to the discomfort of the subject, who up to this time had been seated on a wooden chair. These disturbing factors were removed by putting the subject in an invalid chair which could be adjusted to any desired position. He could rest here comfortably with all his muscles as completely relaxed as if he were in bed. This rendered the volume of the arm much more constant. But the most conspicuous of the disturbing factors still remained. This ~~the~~ ~~was~~ is the mental reaction:apparently every thought that flits across the subjects mind records its presence by a change of volume in the arm.Talking in the room, the entrance of a stranger, the striking, of the clock, or noise in an adjoining room was usually accompanied by a change of volume in the arm, and this, sometimes, even when the subject was asleep. This is what was expected from the correlation which Mosso has shown

to exist between cerebral function and the volume of the arm. I) Nor do I see any way in which this disturbing factor can be eliminated, while working, with sensory stimulation. The only course open seems to be to confine it within as narrow limits as circumstances will permit and to endeavor by control-experiments to differentiate what mental reactions may remain from the sensory reactions under investigation.

The odors were at first administered to the subject by holding a bottle under his nose and allowing him to smell its contents. This was the plan pursued by Lehmann 2) but it is open to several obvious objections. The disturbance of mental equilibrium occasioned by such a procedure is itself sufficient to condemn it. Any sudden or unexpected movement of the operator produces a mental reaction in the subject. On the other hand, I soon found that when he anticipated my movement a reaction appeared. When he saw me reaching for the odor-bottle, even

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I) Op.cit.p. [illegible]
2) Op.cit.p.33.

when I did not apply the stimulus, a reaction appeared which was often very similar to that accompanying the sensation itself.

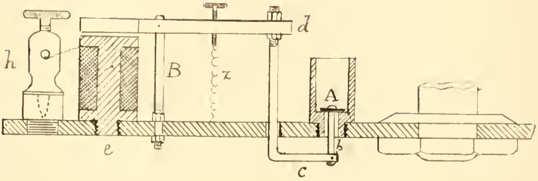
The subject should be isolated and every thing that could attract attention as far as possible removed. A screen was placed between the subject and the Kymograph so as to prevent him from perceiving the recording apparatus or any of my movements.

The apparatus used for applying the odors is shown in plate I. By means of an ~~in~~asspirator m attached to a hydrant-tap, air and cold water are mixed together and poured into a large bottle n. The water is drawn off by a syphon. The air is forced out through a small tube which connects with a coil of lead pipe immersed in a warm bath p of constant temperature. This gives us a constant current of purified air of any desired size at a constant temperature and in constant hygrometric condition. A tube conducts this current of air into a metal pipe r, fastened to the front of a drawer in the Kymograph-table. A series of 13 metal stopcocks open along the up-

per surface of this pipe. In the front of the drawer is arranged a series of I3 bottles, each containing a small portion of oderiferous substance. A pair of small glass tubes perforate the stopper of each bottle and terminate~~s~~ at its lower surface. One of each of these pairs of tubes connects with a corresponding stopcock on the metal pipe. Each of the other tubes communicates with a corresponding glass tube which passes down through the botton of the drawer, bends over to the screen, runs up to about the level of the subject's head where it terminates after passing through the screen. I3 flexible tubes connect these glass tubes with I3 short, metal tubes which are screwed into a terminal plate, and end on a level with its distal surface. A I4 th tubes which does not make connection with any odor bottle, leads directly from the stopcock on the end of the metal pipe to a I4 th ~~meta~~ metal tube in the terminal plate. This permits a current of odorless air to be administered when desired.

The terminal plate is a copper disc, 8 inches

Fig. 3



in diameter, supported from its center on a universal holder which allows it to be adjusted in any desired position. Through this plate have been bored 5 series of 14 holes each, arranged in 5 concentric circles. The odor tubes terminate in the inner circle of holes. The lumen of a short portion of the terminal end of these metal tubes is less than half the diameter of that of their proximal end. 13 of these tubes are provided with electric valves constructed so as to work noiselessly and to leave the face of the plate as free as possible. This prevents the subject from perceiving the opening or closing of the valves, except by his sense of smell, and removes from the face of the plate all objects to which odors might cling.

Figure 3, shows the construction of one of these valves. A metal disc A, faced with rubber-dam is placed in the large end of the tube. The diameter of the disc is less than the large lumen of the tube and greater than its small lumen. A small wire b, passes from the center of this disc out through the small lumen of the tube, and a few millimeters from the

face of the plate, is fastened to a metal rod c, which after running outward parallel with the face of the plate for a short distance bends back at a right angle, passes through a perforation in the plate and is adjusted by two nuts to one end of an armature lever d,This Armature lever runs outward parallel with the plate and terminates over an electro magnet e. It is supported on a pivot B, situated a short distance centrally to the magnet. A small spiral spring z, fastened to the terminal plate is adjusted to the central arm of the lever by a small nut and bolt which allows the tension of the spring to be regulated at pleasure. One wire of the electro-magnet makes contact with the plate, the other passes to an insulated binding screw h, fastened to the plate beside the coil. The tension of the spring is so adjusted as to hold the valve closed except while a current is passing through the magnet, and to prevent the armature from touching the magnet at any time,this prevents noise,and the rubber-dam face renders the valve itself noiseless. The movement of the wire of the face of the

plate in opening or closing the valve is so small that it escapes the notice of the subject.

A wire from one pole of a battery makes contact with the metal pipe of the face of the Kymograph-drawer. Each of the 13 stopcocks, on the upper surface of this pipe, is provided with a platinum contact which, when the stopcock is open, dips into a corresponding mercury well, situated on the upper surface of the drawer between the stopcock and its odor-bottle. A wire passes from each of these mercury wells to a corresponding binding screw thence through the coil of the electro-magnet to the terminal-plate. A wire in contact with the copper, terminal plate passes to the magnet of the signal plate and thence back to the other pole of the battery.

The opening of any of these 13 stopcocks, therefore, sends a constant current of air through the corresponding odor bottle, and, by completing the electric current opens the terminal end of the corresponding odor tube near the subject's nose, and marks the instant

on the paper.

Opening the 14th stopcock, at the end of the metal pipe, sends a current of odorless air through the tube which terminates with the odor tubes.

To secure quiet and exclude light stimulation the subject was at first placed in a separate and darkened room. I soon found that every movement he made produced a change in the volume of the enclosed arm. It was necessary therefore to bring him into my room where I could observe any movement he might make. A screen was placed so as to prevent him from seeing me or the recording apparatus. The room was of course kept quiet and visitors excluded except where their presence is noted. All the records discussed here were taken by the improved form of apparatus described above.

Plate IV.2 is a portion of the record taken from Mr.Reedell on Jan. His arm was in the cylinder about 15 minutes when this portion of the record was begun. Curve E, gives the time in seconds. Ordinates are drawn at every 5 th second. The base-line F, is drawn parallel

to the curve E. The pulse curve D, shows very little change in the heart-rate. There are I9 heart-beats in the first I5 seconds, and I8 in each succeeding I5 seconds. The respiratory curve B, shows no very great irregularities. Curve A, shows that the odor of isobutyric acid was turned on from the I0 th, to the I20 eth, second. The vaso-motor curve C, shows an increase of I.2 C.C. in the volume of the arm during the first I2 seconds. Curve A, indicates that the odor of isobutyric acid was turned on at the I0 th second, but it is evident from the respiratory curve (respiratory phase) that it could not have reached the olfactory membrane much before the I2 th second. At this point, the arm ceases to increase in volume, and, 3 seconds later, it begins to decrease. At the 20 eth second it shows a diminution of I.5 c.c. The curve then slowly returns to the base-line which it almost touches at the 38 th second. It indicates a second diminution of I c.c. at the 45 second. After this the curve rises slowly and crosses the base-line at the 70 tieth second. This is followed at

intervals of about 10 seconds by 3 positive waves and 1 negative wave somewhat less than .5 c.c. This curve would seem to indicate that the odor of isobutyric acid produces a reflex stimulation of the cardio-inhibitory and vaso-constrictor fibers, but I do not think it furnishes sufficient evidence for such a conclusion. The curve frequently shows just the opposite effect. To be at all certain of the effect of any particular stimulation we must, at least, know the general movement going on for sometime before and after the stimulation. To avoid the inconvenient length of the original records needed for such a study, I have condensed the data which they furnish into plotted curves. A number of which accompany this article. The ordinates are at each 10 seconds. Curve A, at the bottom of the plates gives the changes in the amplitude of the pulse waves. The absolute value of this amplitude might easly be determined empirically, but this I have not done. Nor can I calculate it exactly since I failed to keep a record of the magnification used in the leverage of the writing apparatus.

But since this leverage was not changed during any of the individual records, it may be relied upon for the changes which occur during the same record. ~~The~~ Abscissa Each represents about .2 c.c. in volume. Curve D, gives the heart-rate. Each Abscissa for this curve represents I beat per minute. Curve C gives the changes in the volume of the arm in cubic centimeters. Each Abscissa represents a change of .2 c.c. The pulse amplitude and the volume changes are calculated at every 5 th second. The heart-rate is reckoned for every I0 or I5 seconds. The time of stimulation by the various odors is indicated in the plates. The respiratory curve was taken in all the original records, and whenever it represents any marked irregularities this fact is noted on the plates.

In order to study the effects of repetition and individual variation in response to the same odors, the experiments were arranged in 2 series. The first series of experiments were all made on the same subject; the second series were made on I2 different individuals.

Mr. George Bill, who acted as subject in the first series of experiments, is a mechanic 33 years of age in good health, of fair muscular development and not particularly susceptable to odors. His arm was kept in the cylinder about an hour daily from the middle of October to the middle of January. He was trained to keep his mind as blank as possible. The monotony of daily repetition soon removed the disturbances which, in untrained subjects, arise from the novelty of the surroundings. The odors of heliotrope, wood-violet, winter green, musk, skatol and indol were used daily: a few other odors were used occasionally.

Defects in the earlier forms of apparatus used, render the experiments made during October and November unsatisfactorily. Plates V to XI inclusive, give the results of 7 experiments of this series which were made during December and January, when all the conditions were most favorable.

One of the most obvious features of these curves is the general increase in the volume of the arm

which they exhibit during the course of the experiment. Thus experiment V shows an increase of 39 c.c. in the volume of the arm, between the 450 tieth and the 2350 tieth second. Experiment VII gives an increase of 30 c.c. between the I st, and the 1360 tieth second. Experiment XI gives an increase of 35 c.c. between the 20tieth and the 1300 dreth second, and experiment X shows that the arm increased 37 c.c. in volume between I st and the 1900 dreth second.

Several facts indicate that this increase in the volume of the arm is due not to the temperature or pressure of the water in the arm cylinder, but to the mental condition of the subject. The temperature and pressureof the water were the same in a number of other experiments on the same, and on other subjects, where no such general increase in volume occured. Secondly, the volume of the arm decreased immediately when anything attracted the subjects attention. In experiment V the subject was resting quietly with his arm in the cylinder for 10 or 15 minutes before I began to take

the record. During this time the arm increased several c.c. in volume. I00 seconds after the record was begun Dr.K. enetered the room quietly, but was perceived by the subject. The volume of his arm decreased II. 5 c.c. in the following 50 seconds, I50 seconds later Mr.G. entered the room. This was followed by a $\overset{u}{a}$rther decrease of 4 c.c. in 20 seconds. After they both left the room the arm immediately began to increase and continued to increase to the end of the experiment. In experiment X I spoke to him at the 240 tieth second.This occasioned a fall of 5 c.c. in a few seconds.Twice in the course of this experiment I turned on the odor of Formic acid, for a few seconds, each time it occasioned a sudden diminuation in the volume of the arm.

The subject had grown familiar with his surroundings; the chair was very comfortable, the room quiet; there was nothing to attract his attention and as a consequence his mind quieted down, and he was frequently dozing, towards the end of the experiment. In

experiment VII he slept from about the 300 dreth second to the end of the experiment. It will be seen, too, that, in these experiments the heart-rate becomes slower and steadier as the arm increases in volume, thus showing that the subject was gradually quieting down or going to sleep. These facts I think, show pretty clearly, that this general increase in the volume of the arm is due to diminished mental activity; but whatever may be its cause, it must be taken into account in calculating the effect of any particular sensory stimulation. To check an upward movement of the curve is practically the same thing as to cause a downward movement of a curve that is running horizontally. A horizontal line evidently cannot be taken as base line in calculating local changes. The base line must run in the general direction of the curve. It is not an easy matter to determine accurately what this line should be. But in most cases it may be approximated, and a line obtained which will be much nearer the truth than a horizontal would be.

The curves also exhibit two species of local variation which do not seem to be connected with sensory stimulation. In most of the curves small oscila - tions occur which suggest Traube-Herring waves.Besides these,larger and slower changes occur at irregular intervals, which seem to be due to variations in the mental condition of the subject. These changes form the most annoying factor in the curves. I have been unable to eliminate them; and it is very difficult if not impossible to determine the part they play in the volume changes which occur during sensory stimulation.

Some peculiar features occur in plate VII which are probably due to the fact that the subject was asleep during most of the experiment. The arm increased rapidly in volume from the beginning of the record to the I300 dreth second and gradually decreased from this to the end of the experiment. The subject had been resting quietly with his arm in the cylinder for some time before the record was begun. He seemed to be asleep about the 300 dreth second; at the 430 tieth second I spoke to him and found

that such was really the case. He did not wake but his arm decreased 3 c.c. in the following 20 seconds, and then increased more rapidly then before. 75 and I20 seconds later two other falls of about 4 c.c. occured which do not seem to be connected with any external stimulus. At the I930 tieth second 50 seconds after a musk stimulation had ceased, there was a fall of 5.5 c.c. in 30 seconds. At the 2250 tieth second, during an indol stimulation, there was a fall of 6. 6 c.c. in 35 seconds, followed by an increase of 9 c.c. in 265 seconds, when, 35 seconds after the indol stimulation had ceased, there occured another fall of 7.6 c.c. in 30 seconds. The odor of winter-green was now turned on for a I50 seconds, during which time, the volume of the arm increased 4 c.c., 5 seconds later, there was a fall 5 c.c. in 35 seconds. During the following 400 seconds, 4 or 5 similar falls of less extent occur. At the 3I50 tieth second, during a skatol stimulation, the subject woke with a deep inspiration; the heart-rate changed from 56 to 80; the volume of the arm increased 20 c.c. in 70 seconds and presently decreas-

ed almost as rapidly. He spoke to me at the 3250 tieth second and seemed asleep I00 seconds later.

How are these changes in the volume of the arm to be interpreted? The curve, throughout its entire extent, exhibits rythmic changes which suggest Traube-Hering waves. Are the larger changes mentioned above of a similar nature? There is a certain periodicity about them, and, if we except the sudden increase in volume which occured at the 3I50 ~~ti~~eth second, they resemble the smaller changes in all but extent, and, even in this respect, it will be seen that they gradually shade off into each other. It is possible that they are caused by variations in the cerebral activity. This explanation wpuld harmonize with Mosso's observations, on the changes in cerebral circulation during sleep.I) Changes in mental activity invariably causes changes in the volume of the arm; the play of the sleepers imagination may therefore account for changes in the volume of the arm, with which we are here dealing. Some facts in the curve itself point in this direction. The fall at the 430 ~~ti~~eth second was appar-

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I) Op.~~cit.sup~~.cit.p. 7

ently caused by my speaking to the subject. He did not wake, but it is possible that my speaking to him occassioned a dream which caused this and the two following changes. The large increase in the volume of the arm at the 3150 ~~tie~~th second appears to be due, chiefly, to the very great ~~accelel~~ accelleration in heart-rate, which occured at that moment. This was during a skatol stimulation, bur it will be seen from the other records that skatol does not, itself, accelerate the heart-rate. Did the foul odor occasion an unpleasant dream in which some spasm of emotion caused the sudden increase in heart-rate and wake the subject? Speculation concerning the orign of these changes, however, will be ~~made~~ of little value until we have more data at our disposal. The question which immediately concerns us here is whether or not when all due allowances are made for changes produced by other causes, the curve still presents any evidence of sensory reactions. We will be in a better position to answer this question after we have made a comparative study of the other curves. The odor of formic

acid was administered once for a few seconds in experiment IX and twice in experiments VI, VII, and X. Each time it prevented full respiration and caused a sudden and quite large decrease in the volume of the arm.The same result was invariably obtained whenever I used formic acid. Lehmann I) obtained similar results with ammonia and bisulphide of carbon, which he used as typical unpleasant odors, I think, however, that the reaction in these cases are due in greater measure to the irritating action of these substances on the terminations of branches of the trigeminal nerve in the mucus membrane of the nose than to their odors.

In experiment VIII acetic acid was administered at the I260 tieth and again at the I4I0 th second. Each time it produced a diminution of 9 c.c. in about 50 seconds. It was also administered in experiment VI at the I400 dreth sedond, in experiment X at the I450 tieth second and at the end of experiment XI but in none of these cases did it produce any marked reaction. The cause

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I) op.cit.p.34.

of this descrepancy in results is not apparent.

Propionic, butyric, isobutyric, and valeric acids were administered on several occasions without any very decisive reactions appearing.

In experiment VI propionic acid was administered at the 2225 th second. A fall of 4 c.c. occurred during the 35 second of the stimulation;but it is not at all certain that this fall was due to the acid, since similar falls occur throughout this curve without any apparent dependence on sensory stimulation.In experiment VIII at the 2160 tieth second the volume of the arm increased 3 c.c. during the first 40 seconds of a Propionic stimulation and decreased I.8 c.c.during the remaining 20 seconds. But this stimulation followed immediately upon a fall of II c.c.produced by formic acid. The curve usually rises in this manner in such cases without any sensory stimulation. The fall during the latter part of the stimulation was possibly due to the acid. Propionic acid was administered again ~~th~~ at the I870 tieth second, in ex-

periment X there was a rise here of 1.5 c.c. during the 20 seconds of the stimulation, but this rise is in the general direction of the curve and presents no evidence whatever of a sensory reaction. In experiment VI Butyric acid was administered from the 1710 th to the 1890 tieth second, and valeric acid from the 2000 santh to the 2175 th second. Falls occurred in both instances; but from the general movement of the curve it would appear that they are rhythmic contractions, and independant of the stimulations. At the 1920 tieth second in experiment VIII the curve was rising rapidly and continued to rise, apparently uninfluenced by the butyric acid which was turned on during the following 50 seconds. At the end of the stimulation the curve took a horizontal direction which it kept during the following 130 seconds. Valeric acid was administered during 75 seconds of this time without producing any apparent effect. Butyric acid was also administered at the 1715 th second in experiment X. A fall of 2 c.c. occured during the first 30 seconds, but the curve shows that this also may be a

rythmic contraction. Isobutyric acid was used once in each of the experiments VI, VIII, IX, X, and XI without any apparent effect.

Besides formic acid, and the two instances of acetic acid mentioned above, there ~~was~~ are three other causes which, when present, usually cause a marked diminution in the volume of the arm. These are, a deep inspiration, muscular movement and mental work. A typical effect of a deep inspiration occured at the 1070 tieth second in experiment X. This diminution in the volume of the arm seems to be due in part to the negative pressure in the pleural cavity, and in part to the contraction of the respiratory muscles, but I believe the largest factor in the production of this reaction is the change in the mental condition of the subject, which usually accompanies an inspiration of this kind. On such occasions the subject is usually drowsy. With the deep inspiration the mind brightens temporarially. It would seem that there is a constriction of the peripheral arteries, causing the increased flow of blood to the brain.

When a deep inspiration occurs, while the mind is bright, there is seldom any very large decrease in the volume of the arm. It is possible that when this change occurs during an odor stimulation, the stimulation also takes part in its production, but if so, the effect of the odor cannot well be isolated. It is better, therefore,for present purposes, to discard such reactions. At the 2940 tieth second in experiment VI I requested the subject to move his foot, which he did during the following 50 seconds. The heart-rate immediately changed from 72 to 92, and after 30 seconds gradually returned to its former rate. This sudden increase in heart-rate caused a transitory increase of 6.5 c.c. in the volume of the arm followed by a decrease of 13 c.c. in 50 seconds. In this case it is probable that the effect was due in part to the muscular work and in part to increased mental activity.Whenever he moved his foot unconsciously, as he sometimes did, as at the 1670 tieth second in this experiment, it produced a slight decrease in the volume of the arm;but of course there was not nearly the same amount of muscu-

lar work in these cases as in the instance referred to above.

The curves furnish numerous illustrations of the effect of mental work. It always causes a decrease in the volume of the arm. A typical instance of this occurs at the I00 dreth second in experiment V. Sometimes the fall is preceeded by a transitory rise as at the I390 ~~ti~~eth and 2940 ~~ti~~eth seconds in experiment VI but in all such cases the rise is evidently due to a sudden acceleration of heart-rate. Besides these changes which can be definitely accounted for, the records of this series of experiments show a number of other variations in the volume of the arm. The general movement of the curve has already been discussed. In all the curves small oscillations occur every few seconds which are very much more pronounced in some records then in others; but which remain pretty much the same throughout the entire extent of the same record. These facts indicate that they are influenced by the condition of the subject rather than by any particular stimulation.

When due allowance is made for all these changes do the records of this series of experiments present any evidence of pure odor reactions?

White heliotrope, wood-violet, winter-green, and musk were chosen as specimens of pleasant odors; skatol and indol~~e~~ as unpleasant odors. The subject enjoyed the first four very much and disliked the latter two.

Heliotrope was administered at the 1365 th second in experiment V; at the 220 ~~tie~~th and 2740 t~~ie~~th seconds in experiment VI; at the 210 th and 2300 ~~dre~~th seconds in experiment VII; at the 45 th second in experiment VIII;at the 850 ~~tie~~th and 1910 th second in experiment XI.In none of these instances is there any clear evidence of a reaction. There is not one feature common to these various curves, There is scarcely a resemblance between any two of them. The only approach to a resemblance among them is the upward tendency of the curve; but this is in the general direction of the curve and evidently is not due to the stimulation.

What has ~~been~~ here been said of heliotrope,applies

with equal forces to the other five odors mentioned. Violet was administered at the 430 ~~tieth~~ second in experiment VI. The volume of the arm increased 2 c.c. in the first 30 seconds and decreased 4.5 c.c. in the following 30 seconds; it then increased to the end of the stimulation. Indol was administered at the 920 ~~tieth~~ second in the same experiment with very similar results. At first sight, these look like odor reactions. But it will be seen that the five other similar falls occur in the first 1000 seconds of this experiment, at approximately equal intervals of time. The first two falls occur before any odor was administered; the third, fifth, and sixth occur in intervals between stimulations. The latter portion of the curve presents a similar series of falls. Besides, if the falls occurring during the Violet and Indol stimulations were odor reactions we would expect that they would occur with some regularity in repeated experiments on the subject; but such is not the case. It is altogether probable therefore that we are not here dealing with sensory reactions, but with rhythmic contractions

of the blood vessels. A comparison of the curves obtained by repeated applications of any one of these six odors will make it clear that if the stimulation had any effect on the volume of the arm it is very thoroughly masked by other movements of the curve. If the odors really produce any characteristic effects they would come out in a composite curve made from a large number of experiments. I have not yet a sufficient number of experiments to give any value to such a composite curve.

The experiments given here are essentially similar to a number of other experiments made on the same subject, all of which were conducted with great care;but the results obtained do not justify any such conclusions as those which Lehmann deduces from his experiments.

" Jeder lusterregende Eindruck erzeugt eine Vergrösserung des Volumens des Armes und der Höhe der einzelnen Pulsschläge nebst einer Vergrösserung der Tiefe des Atemholens."I)

" Einfache, unlusterregende Sinneseindrücke rufen, wenn sie schwach sind, sogleich eine Verminderung

des Armvolumens und der Höhe der einzelnen Pulsschläge hervor. Das Volumen nimmt bald wieder zu, trotz der Verkleinerung der Pulsschläge,~~ihre~~ und überschreitet gewöhnlich die Norm, wenn die Pulsschläge ihre vorige Grösse erreicht haben, die übrigens im allgemeinen ebenfalls überschritten wird. Bei stärkeren, aber doch nicht schmerzhaften Eindrücken treten diese Veränderungen mehr hervor und werden zugleich unmittelbar nach Anfang der Reizung von einigen tiefen Atembewegungen begleitet." 2)

" Einfache lustbetonte Sinnesempfindungen werden von einer Gefässerweiterung begleitet und vielleicht auch zugleich von einer Vergrösserung des Umfanges der Herzkontraktionen in Verbindung mit einer Erhöhung der Innervation der willkürlichen Muskeln, jedenfalls der Atmungsmuskeln. " 3)

An inspection of the curves of this series will

I) ~~op.cit.p.32~~.
2) Ibid. p.89.
3) Ibid. p.

satisfy one, that none of these statements is true of them. Heliotrope and wood-violet are certainly pleasant odors and were enjoyed by the subject: yet, the volume of the arm diminished quite as often as it increased, during their application. Indol~~e~~ and skatol are unpleasant odors, yet the volume of the arm frequently increased during the first few seconds of their application and then decreased. It is not certain however that any of these changes were pure odor effects.

The second series of experiments were made on 12 students, ranging from 20 to 30 years of age. Each experiment lasted about an hour. The same odors and acids were used as in the former experiments. There are some features common to all these experiments.

In the first couple of experiments with each subject the curve exhibited very little of the tendency to rise which constituted such a prominent feature of the first series of experiments; but this tendency became more pronounced in the 3 rd and 4 th experiments. Where the general tendency of the curve is upward the

heart-rate also becomes slower and steadier. This supports the view advanced above that the gradual increase in the volume of the arm and the slowing of the heart-rate are due to the diminished mental activity. The small oscillations in the curves are, as in the former series, characteristic of the experiment. They are much more pronounced in some experiments than in others, but remain pretty constant throughout the entire extent of the same experiment.

The reactions in all the experiments are in the same direction, but they vary in extent with the different subjects, with the subject at different times, and with the different stimuli.

Plate XII will serve as an illustration of the reactions obtained from subjects who are sensitive to odors. This was the 3rd experiment on Mr.D. who is a student about 22 years of age, of rather slight build, and nervous temperament.

The amplitude of the pulse wave diminished to about one half at the first odor stimulation, and did not

again return to its original size. The heart-rate ~~sows~~ slows up considerably during the experiment. The general tendency of the volume-curve is slightly upward.

The subject was resting quietly, with his arm in the cylinder for 10 or 15 minutes before the record was begun. During this time, and for the first 370 seconds of the record itself, the volume of the arm increased slowly, without exhibiting any very marked changes. Heliotrope was administered from the 370 ~~tieth~~ to the 725 th second. During the first 50 seconds of this period the volume of the arm decreased 19.5 c.c. It increased about 1 c.c. during the following 50 seconds, and 14 c.c. during the next 125 seconds. This was followed by a fall of ~~4~~ 4.5 c.c. in 25 seconds and a rise of 7.5 c.c. in 100 sedonds. The prompt fall at the beginning of the stimulation, and the fatigue effect after about 100 seconds, are pretty good evidence that this is an odor reaction, especially when it is taken in connection with the ~~a~~ character of the curve previous to the stimulation. This conclusion is confirmed I think by the

fact that a similar reaction was obtained every time I used this odor on Mr.D. Two other heliotrope stimulations occur in this record with results very similar in everything but extent; and this difference is, at least partially, accounted for by the fact that at the 740 ~~tie~~th second I moved the terminal plate farther from the subject's nose so as to diminish considerably the strength of the stimulation.

The fall of I8 c.c. which occured between the 740 ~~ti~~eth and the 790 ~~ti~~eth second is a mental reaction caused by my speaking to the subject, and readjusting the terminal plate. When the volume of the arm ha~~s~~ returned to about its former condition and seemed inclined to remain pretty steady, I turned on wood-violet. It will be seen that the reaction is very similar to the previous heliotrope-reaction, only less extensive. There is a fall of 8.4 c.c. in the first 30 seconds. It remains down about 25 seconds, and increases 6.5 c.c. in 70 seconds when a second fall of 3.7 c.c. occurs. Winter-green was turned on from the I265 th to the I440 tieth second,

the reaction is very similar to the previous violet-reaction, in every respect but the extent of the second fall. I had requested the subject before the experiment begun to leave his mind as blank as possible, and not even to speculate about the nature of the odors.The reactions were so large, however, that I suspected the presence of a mental reaction, and accordingly at the I500 dreth second, I turned on a current of odorless air strong enough to be felt on his face. When the experiment was over I remarked that he had not obeyed my instructions, but was indulging in speculations concerning the odors. He assured me that such was the case on only one occasion for a few seconds, when he felt the air coming from the tube but could percieve no odor. This indicated that the reactions in the other instances are connected in some way with the odors.At the I550 tieth second, heliotrope was again administered.There was a prompt fall of I0 c.c. in 35 seconds, followed by two quite large falls during the course of the experiment. After an interval of I50 seconds during which time there

was very little change in the volume of the arm. Musk was turned on. It occasioned a prompt fall of 8 c.c. in 20 seconds. The two secondary falls were very slight. Skatol e was turned on from the 2640 tieth to the 2740 tieth second without any apparent effect. Heliotrope was administered for the 3rd time at the 2730 tieth second. The reaction is essentially similar to the 2 former instances. I spoke to him at the 3030 tieth second. An aquaintance enetered at the 3150 tieth second. When the subject had quieted down I turned ~~a~~ on formic acid for 35 seconds. It caused a fall of 18 c.c. in 50 seconds. This record and a number of other records of this series give abundant evidence of odor reactions. But the reactions whenever present were always in the same direction.

Summary.

The most important outcome of this investigation has been the completion of various improvements in the construction and use of the plethysmograph, by means of which numerous errors attending the use of the instrument have been elim-

inated.

The result of the work shows that all olfactory sensations, in so far as they produce any effect through the vaso-motor system, tend to diminish the volume of the arm and therefore presumably cause a congestion of the brain. Whenever the stimulation occasions an increase in the volume of the arm as sometimes happens it seems to be due to accel~~l~~eration of the heart-rate, which of course tends also to increase the supply of blood to the brain. The effect varies in extent with different individuals and with the same individual at different times.The effect ~~was~~ is most marked in subjects sensitive to odors. Irritant vapors such as formic acid ha~~s~~ve a marked effect in the same direction. The experiments give no support to the view that pleasant sensations are accompanied by a diminution in the blood supply to the brain and unpleasant sensations by the reverse effect.

In all my experiments, mental work caused a marke and prolonged diminution in the volume of the arm. This vaso-motor effect was somrtimes preceeded by a transitory

increase in volume of the arm caused by accelleration of heart-rate.

Biography.

Thomas Edward Shields was born upon the 9 th of May, in the year I832 at Mendota, one of the suburbs of St.Paul, Minnesota. In I882 he entered the sophmore class of St. Francis College Milwaukee and remained there until I885, completing its classical curriculum. In September, I885, he began his philosophical studies in the theological seminary of St. Thomas Aquinas at St.Paul. Here he passed six years: 2 years in the study of Mental Philosophy, Ethics, and the physical sciences; and 4 years in the study of Theology- Dogmatic and Moral-, and the accompanying branches of Holy Scripture, Church History, and Canon Law. He was ordained priest upon March I4 th I89I; and, on the following June, was assigned as Curate to the Cathedral of St.Paul. After fourteen months in the active ministry there, he came to Baltimore (in September I892), received the degree on Master of Arts from St.Mary's University, and began his studies in the Biological Department of the Johns Hopkins University, in October of the same year.

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Plate IV.

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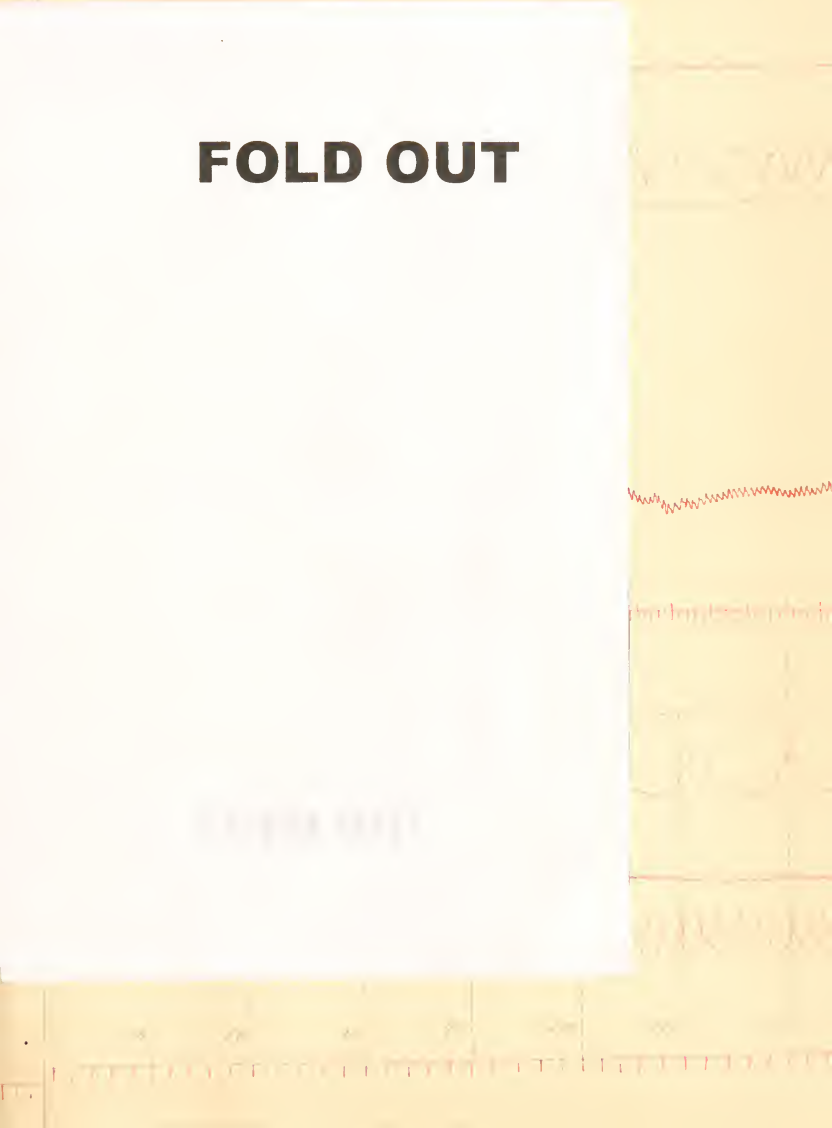

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